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ABSTRACT

This paper is designed to fill the need for an easily understood introduction to the computing and data processing field for the layman who has, or can expect to have, some contact with it. Information provided includes the unique terminology and jargon of the field, the various types of computers and the scope of computational capabilities, and some rules of thumb which can be applied in determining whether a need for such a capability exists or not. (RAO)

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COMPUTERS AND INFORMATION FLOW

R. L. Patrick

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COMPUTERS AND INFORMATION FLOW

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PREFACE

This Paper is a talk which is being given to interested audiences under a program established by the University of California. It is aimed at the person who has no knowledge whatsoever of the computing and data processing field, but who has, or can expect to have, some connection with it.

The lecture's purpose is to provide a general introduction to the field, to pin down its unique terminology and jargon, to identify the various types of computers and the scope of computational capabilities, and to provide some rules of thumb which can be applied in determining whether a need for such a capability exists or not.

Although the audiences to date have been primarily from the business world, the remarks should also be valuable to many others who have incidental contact with computing, particularly in the military sphere and in education. The Rand Corporation feels that this Paper helps to fill the need for an easily understood introduction to computing for the person who requires only a layman's knowledge of the field.

The original version of this Paper (October 1963) was prepared for presentation at a series of lectures under the auspices of University of California Extension.

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COMPUTERS AND INFORMATION FLOW

The mathematics for astronomical computations, scientific and engineering design, decision making, modeling and simulation, and adequate project control, have, to a greater or lesser degree, existed for many years. However, the exploitation of these areas was hampered--although not stopped--by the lack of a suitable device to rapidly and economically manipulate them. In short, we did not have an economic tool for handling these classes of mathematics and their related data. Following World War II the electronic computer made its debut. The first learned paper which described its existence, as we know it now, was published in 1946 by Von Neumann, Burks, and Goldstein. In the short period of 31 years, a period shorter than the time since some of you received your first college degree, the computer has sprung from the gleam in the eye of a recognized genius to a multi-billion-dollar-a-year business.

intro

The available time is too short to attempt to convert you into computer experts. Instead, I shall try to introduce you to the field, describe some of the constraints on us and our operations, and then try and explain what all of this means to YOU, whom we endeavor to serve.

A computer is a very expensive electronic-mechanical device. In order to produce a device and write the engineering costs off over a large production volume, the device must be designed to have broad appeal to a wide variety of users. We call such a device a general-purpose digital computer. A general-purpose device can be used with practical efficiency across a broad spectrum of problems. To be sure, a specialized device will likely out-perform a generalized computer, but, since it would have limited appeal, the purchaser must be willing to bear all of the development costs himself, as is true for any piece of custom-designed equipment. About the only market for special-purpose computers today is a very specialized market, such as process control, or in-flight computers where minimum weight dictates custom design. Thus, we find we have two kinds of digital computers: the special-purpose computer which is very efficient, custom-designed and expensive (relatively); and the general-purpose computer which is less expensive and applicable to a broad range of problems.

general-purpose digital computer

special-purpose computer

In addition, there is another kind of computer with which some of you may be familiar, called the analog computer. One kind of analog computer uses voltage levels to represent quantities and performs its

function by simulating (yes, true simulation in every sense of the word) the physical phenomena being considered. Thus, we may predict how the physical phenomena would respond to various stimuli. Analog computers are excellent for simulation purposes and are widely used. However, they suffer from accuracy limitations and are also somewhat limited in the number of problems per day which they can solve due to their set-up limitations.

analog computer

Since the special-purpose computer must be integrally designed into any system that one considers, and since the analog computer is more or less limited in its applications, the remainder of our attention will be directed towards the general-purpose digital computer. The previous speakers in this series have dealt, more or less exclusively, with general-purpose digital computers, although they may not have been meticulously careful to make this clear. The general-purpose digital computer is a compromise design marketed by the computer manufacturer who endeavors to get a broad market (and hence sales volume) for a single engineering design and marketing effort.

Furthermore, the word digital has a very special meaning since information is represented internal to the machine as numbers (and not by voltage amplitudes). Each quantity retains its original accuracy and significance

digital

accuracy and significance

throughout the entire process. Thus, the general-purpose digital computer retains the accuracy commonly attributed to the bookkeeper while enjoying the dynamic range of problems usually considered by the engineer.

A digital computer is a tool used to process information. The advantages of computer processing of information over other modes of processing are increased accuracy, compression of elapsed time, and economy. The classical organization of computer hardware dictates that each information processing task be subdivided into three major functions: input, compute, and output.

These three basic functions can be implemented in a

input

variety of ways depending on the requirements of the processing task. Input information is usually contained on some combination of the following media: 80-column punched cards, punched paper tape, magnetic tape, communications lines, or special instrumentations such as the azimuth or elevation readouts of a radar. The information contained on such input media is made available to the compute. by a variety of input devices, such as 80-column card readers, punched paper tape readers, magnetic tape transports, or buffer and control circuitry required for communications lines or special instrumentation devices.

After processing, the information may be output

output

from the computer onto one of several recording media.

These media are: printed pages from a high-speed printer (hard copy), 80-column punched cards for subsequent processing, magnetic tape for either immediate or delayed re-use, automatic messages prepared for direct entry into a communications network, or a control signal into a myriad of special-purpose action devices. Depending upon the requirements of the processing task, a system designer may choose from such readily available output devices as line printers, card punches, magnetic tape transports, and punched paper tape devices. In frequent instances a typewriter-like terminal or a Cathode-Ray Tube (CRT) keyboard/display connected to a communications network provides both input and output. Or a user may select special-purpose gear to meet his unique requirements.

compute

The compute function is performed on a highly integrated device having two primary parts: 1) a store; 2) an arithmetic and control unit. A large high-speed electronic store receives information from the input units, retains intermediate products of computation, and builds up the final output.

stored programming

For the class of general-purpose machines to be discussed here, this store is also used to retain a coded version of the processing procedure. This form of computer organization is credited to Von Neumann; the scheme is called stored programming. Currently,

the constituents of a large store are magnetic cores. Core storage usually has a uniform rapid access to any information stored within it and a relatively high unit cost per quantity of information stored. The input-output devices and core storage are governed by the arithmetic-control unit. The circuitry associated with this control unit controls the reading of new information, the access to information in core storage, and the recording (on an output device) of processed information. In addition, the arithmetic-control unit contains special circuitry for the usual arithmetic operations (add, subtract, multiply, and divide); the logical operations (fetching information from core storage, recording information in core storage, and comparing two items of information); and simple decision processes (e.g., testing the algebraic sign of a quantity and, on the basis of this test, taking one of two alternate computational paths).

An additional type of hardware is often incorporated into the above organization. The core device is a relatively expensive way to obtain storage capacity. For this reason core storages are usually constructed large enough to contain only information frequently used. Information which is occasionally used is retained on auxiliary storage devices.

auxiliary storage

Frequent examples of auxiliary storage are such magnetic media as magnetic tape units, magnetic drums, or magnetic discs. They can store information semi-permanently and retain such information for extended periods of time. Magnetic tapes have high capacity, are serial in character, and can be removed from the computer and shipped or stored. Magnetic drums are intermediate in capacity and retain information as magnetized spots on a metal cylinder that rotates at constant speed. Therefore, information is available to the computer in a cyclic fashion.

tapes

drums

In an effort to overcome the capacity limitations of a magnetic drum while still retaining the cyclic feature, magnetic discs were developed. The surface area available for recording has been greatly increased by mounting several large discs on one single shaft and rotating the shaft at constant speed. Discs have the cyclic characteristic common to magnetic drums. Some magnetic discs are removable and can be shipped and stored like tapes.

discs

The last three mentioned devices--magnetic tapes, drums, and discs--are termed secondary storage; core or other electronic devices are termed primary storage. Primary storage is that storage which is most closely associated with the arithmetic and control unit. Secondary storage appears to the computer as an

input-output unit. Although the time required to obtain a specific item of information from any secondary storage unit is considerably higher than the time required to obtain a similar item from core storage, the per unit cost of secondary storage is significantly less than the per unit cost of core storage.

Two terms, common to the computer field, are almost self-explanatory yet cause some confusion among managers. These two terms are hardware and software. The definition of hardware is fairly well accepted; I quote from the latest Federal glossary, "hardware: the physical equipment or devices forming a computer and peripheral equipment. Contrasted with software." Thus, the devices we have discussed are hardware.

hardware and software

A general-purpose digital computer, as it is delivered by the manufacturer, is incapable of performing any useful function. As was mentioned before, "this store is also used to retain a coded version of the processing procedure." The statement could even be made stronger: the store must be used in this manner or useful work cannot result. This coded version of the processing procedure we call a computer program. It is the result of a series of meticulous steps by a human programmer and, once completed and checked out, adapts this general-purpose device to a specific task.

computer program

The computer itself has been harnessed to aid programmers in the preparation of applications programs. This is a form of bootstrapping: the computer is used to help prepare other computer programs. The programs which perform this assistance are called software. These are programming aids supplied by the manufacturer to assist programmers in the preparation of applications programs.

In the early days of the field these programming aids were produced locally by each individual installation. We finally decided to moderate our requirements somewhat and the manufacturer produces these once, for all the users of a given line of equipment. He graciously adds a little bit to the bill each month to cover their cost. I quote again from the same Federal glossary, "software, the totality of programs and routines used to extend the capabilities of computers, such as compilers, assemblers, narrators, routines, and sub-programs. Contrasted with hardware."

software

One special type of software is called a control program. This is a supervisory program that provides for the efficient non-stop operation of a large computer. This control program is usually provided as an integral part of the computer system by the manufacturer. It dynamically schedules work so the computer's resources

control program

are effectively used, monitors the status of jobs in progress, provides certain common services used by all of the jobs in the job stream, handles all communications with the operator, and keeps accounting and other vital records so the charges for services are equitable and restart is possible in the event of a catastrophe.

Modern control programs allow the resources of a computer to be dynamically allocated to two or more jobs at the same time. Thus when one job is waiting for the completion of an action by an electro-mechanical I/O device, the rapid (and expensive) electronic circuitry can be assigned to another task during the interim. The speeds with which a modern computer operates are almost unfathomable. Two numbers may be added in a millionth of a second. A record may be obtained from a disc file in a tenth (.1) of a second. Task switching can be performed by the control program in one ten-thousandth (.0001) of a second. The process of rapidly switching from task to task while keeping all of the I/O devices fully utilized is called multiprogramming. It is the standard mode of operation for all but the very smallest computers.

multi-programming

With the rapid advance of electronic technology, many small manufacturing firms have entered the computer field

and have successfully produced general-purpose digital computers which are small in size and capacity, but utilize the same ultra-fast circuits as the larger machines. These are called mini-computers and can be purchased for less than $10,000 including a punched paper tape reader, and a teletype terminal to be used for input and output. These computers come with minimal software and are primarily used as a control component in some larger system to switch a communications network, to control a factory process, or to monitor special instrumentation as in a hospital intensive care ward.

mini-computers

The strongest single trend in the computer field today is towards large concentrations of computer power connected by communications lines to a geographically decentralized population of users. The users access the computer through a variety of on-line terminals which provide for remote job entry (RJE) via card readers and printers, direct data input through teletypewriter or CRT terminals, or a variety of other input/output devices. The central computers handle many varied job streams using multiprogrammed software and maintain large files of structured data in permanent residence on discs or drums. If the files are structured so they may be referenced by

on-line terminals and regular job streams, and if the proper controls are installed to protect the integrity of the data, the software will have been extended to provide data base management functions. Thus the system can allow remote inquiry into the data files, on-line immediate file update as required, and constant sharing of these master data files between the on-line applications and the more traditional batch processing activities.

data base management

Thus we are beginning to get a view of a computer service center. Generally, the computer service center does not directly produce a saleable product, but merely exists to assist other operating units of the organization. In the performance of this function, it is a service center in every sense of the word, just as accounting, drafting, and housekeeping are service functions. They are all required, but contribute indirectly to the profitability of the business.

Before we proceed with our computer center discussion there are one or two major considerations which should be understood. Since the computer industry is changing so rapidly, most of the computers in the field today are rented. The manufacturer takes the risk of obsolescence and the user invests his risk capital elsewhere. The monthly rental for a computer covers

the rent for the machine, its maintenance, and spare parts. In a field changing as rapidly as ours, the purchase price of a machine is usually 40 to 50 times its monthly rental. rental agreements

For your basic rental dollar you acquire such a machine for only 176 hours per month. This is called basic single-shift usage, and is roughly equivalent to eight hours a day, five days a week. If you require more computing capacity than single-shift, an additional use charge is assessed. Typically, this charge is only 10 percent of the first shift hourly cost. Thus, you have a full two-shift operation for only 110 percent of the basic rental agreement. Similarly, three-shift operation costs only 120 percent of the basic rental rate. The manufacturers thereby encourage a smaller manufacturing volume and a faster write-off on the volume produced. This, in turn, affects the attitude of the installation manager and his relationships with his customers. The installation manager is sitting on top of a huge capital investment and he is inclined to exploit it on a multi-shift basis.

With some obvious exceptions, a good rule of thumb for the total cost of such an installation is to double the basic machine rental. A computer can run from about a $1000 a month rent (small), through the medium total cost

price range ($20,000), up to the large processor which rents for approximately $80,000 per month. A single shop which consists of one IBM System/370 Model 168 (at $112,000 per month rent), ancillary computers for handling input-output functions, the programming staff, and the related overhead would cost approximately $250,000 per month, or $3,000,000 per year. If we only ran this machine single-shift, the total cost per hour of operation would be $1420!

This accounts for another peculiar whim common to installation managers. They are highly efficiency-oriented. They get this way and stay this way due to frequent budgetary reviews and checks by higher management. In many cases the computer facility is the largest single item in a corporation budget. Therefore, the budgeteers appear more frequently at our doors to make sure that we are spending our sums properly.

large budget item

As we mentioned earlier, programmers are an integral part of the program preparation process. They meet with customers, extract problem statements from them, muse over these problem statements, return for more information, program the process for the machine, check it out, run some pre-production test cases, and proceed to work out the deficiencies with the customer. As a by-product of this, they document the procedure.

programmers

A useful by-product of this documentation is a problem statement, available to the customer, perhaps for the first time.

The programming field (and the computer field as a whole for that matter) has grown up like Topsy. We're the products of our environment rather than the result of a concerted training and education program. There are some indications that this is beginning to change, but, at the present time, programmers are both the biggest boon and the biggest bane to an installation manager. We're usually overpaid for our experience and education and sometimes inclined a little towards the prima donna. We are faced with huge responsibilities and in many cases work with little or no direct supervision These things are all frustrating, to say the least. Some of you who have been or soon will be directly associated with the computer operation will experience some of this frustration. You do not have the proper background to communicate properly with a programmer (your attendance at this forum is a certain admission of that fact) and he probably similarly lacks the requisite knowledge of your specialty. Through seminars and symposiums such as this we will gradually break down this communication barrier and improve operations by educating both parties to the discussions.

programming field

communication barrier

advantages of computer processing

Much earlier we stated that "the advantages of computer processing of information over other modes of processing are increased accuracy, compression of elapsed time and economy." At this point, it seems appropriate to enumerate some classifications of computer applications which we have found to be useful. There are seven of these.

scientific application

The first one is somewhat of a misnomer but persists in the field, hence we must discuss it. This is the so-called scientific computer application. The term originated since many of the early computer applications grew from the fields of science and engineering. These applications have the characteristics of relatively little input and output and a high volume of arithmetical computations which are liberally sprinkled with multiplications and divisions.

business application

Another term, also somewhat of a misnomer, is the business application. This term was generated by the early predominance of accounting applications which were characterized by extremely high volumes of input and output, little computation, and rather simple decision processes.

Although these two terms are traditional within the field, they are beginning to lose their original significance since many of our modern scientific and

engineering applications have heavy compute and heavy I/O (input/output). Furthermore, our business applications are tending more towards the integrated data processing application wherein the total processing per unit of input data is greatly increased. Thus, these two areas are gradually growing together.

Another pair of terms very much in data processing literature today are batch and on-line. These two adjectives are used to modify the noun "process." With batch processing we gather our transactions into economical groups called batches. We then treat the entire batch as a unit and process it with a computer. This is no more or less than an adaptation of popular techniques in both accounting and manufacturing. If one does not have enough accounts-payable to occupy a clerk full time, the accounts-payables are allowed to accumulate for a reasonable period and then one clerk is assigned to clean up this small backlog. In a similar way if one had some sort of an automatic machine tool, such as a turret lathe, the setup costs would be high. We would schedule fairly long production based on the same setup to use the machine effectively. The computer operations manager has adopted this technique for the same reasons.

batch process

On the other hand, on-line processing was developed by the field in response to customer's demands

on-line process

for time currency. Some applications (not in the majority by any means) profit materially from management's knowledge of the instantaneous status of things. This dictates that transactions be processed as they are received rather than collecting them and batch processing them. As you might imagine, the entire organization must be tuned to such processing. The first applications in this area were in fire control and missile guidance. In the late 1960s, several non-defense applications resulted, one of the more popular being on-line manufacturing scheduling, such as is performed in the Lockheed-Burbank plant.

In manufacturing a large complex assembly, a workable schedule is first designed. Once such a schedule has been adopted, management is intimately concerned in any deviations from the schedule. Their first concern is, "Can I get it back on the original schedule?" Their second concern is, "O.K., if one part is going to be late, can I use this extra time to increase my profits by adjusting some related schedules?"

A special example of the on-line operation is the real-time operation. Before we discuss real-time, we should sharpen our definition of on-line a bit.

on-line

A computer is frequently said to operate on-line. Where human frailties require the support of a computer

in a line position (juxtaposed to a staff position), the computer is said to be on-line.

Frequently, people can conceive and design situations which are beyond the scope of human capabilities. These may involve some combination of extremely high accuracy, voluminous data, or extremely (relatively) short response time. One solution to such a dilemma is to install an on-line computer. In this type of operation the computer must operate as reliably and flexibly as its human counterparts. Sometimes special consoles, special hardware, and/or direct communication lines are associated with this type of operation. If time is not critical, on-line operation does not preclude batch processing.

Occasionally, a computer exists on-line in an unforgiving environment, which is not and cannot be made subservient to computer control. Usually a real-time physical process is involved. If the time available for solution is only slightly larger than the time required for computation, the environment is said to be real-time.

The aforementioned cases of fire control and missile guidance were examples of real-time computer applications. Other examples are telephone switching, and the control of roadway traffic signals.

process control

One type of on-line operation occurs with sufficient frequency to be mentioned here. It is an application known as process control. The process control field is about equally populated with special-purpose computers and with general-purpose computers. In process control the applications are rather specialized, the computer is used on-line in a control capacity, and the resultant process is actually under control of action devices stimulated by the computer's outputs.

In electric utilities, the control of large alternators is one such applications area. Several large steam-turbine-driven generators are placed under the control of one computer. The computer keeps track of the consumption on the line and matches the generator's output to the needs of the consumers. This is done by bringing generators up to speed, synchronizing them with the line, and placing them on the line to carry a portion of the load. The generators so ganged then have their outputs adjusted throughout their part-load range to minimize their operating costs while satisfying the consumer demand. This is an on-line real-time computer application.

Another example is at Standard-El Segundo where a portion of the refinery is being dynamically controlled

by an on-line digital computer. Similarly, an on-line device is controlling the output of a cement plant in Riverside to minimize the amount of unusable waste produced by the kiln.

A special type of on-line process is called command and control. This is usually characterized by the sheer magnitude of the task, the complexity of its solution, and the amount of Federal funds expended in its pursuit. You may have heard of the large Air Force "L" systems which are rather frequently in the news. These are command and control systems. The most widely known of these is the SAGE system which was our original large nation-wide air defense system. It received its basic data from communication lines attached to search radars and had as its primary output displays to human control officers. These displays, if accepted, became automatic output messages to defensive armaments.

command and control

Earlier it was said that this session would help YOU. Perhaps the best way to accomplish that is to supply you with the five symptoms that usually accompany a latent computer application.

five symptoms

1) Any volume operation where the processing can be defined. It is not necessary to define all processing. It must be possible to define the repetitive portion and be able to describe the

volume operation

exceptions in order that the computer can select the exceptions for human action. This is clearly the predominant characteristic of most of our large business data processing, manufacturing scheduling, accounting, labor distribution, payroll, and inventory control applications. The required processing per item is usually not severe, but the sheer volume of items to be processed makes it economical to tool up and perform this processing on a computer.

complex job

2) Any extremely complex job is a candidate. It is not necessary for a job to occur in volume, if it is complex enough. Some things have so many separate steps that people just cannot concentrate for a sufficient period to perform them adequately.

The complexity factor is usually prevalent in most of our so-called scientific or engineering tasks. True, we did accomplish them in earlier years with tables and computresses, but we were required to make rather astute engineering judgments to simplify the calculations involved. The full-blown calculations were too formidable to contemplate by hand. Some of you may remember when we had a very complex job that just had to be right, we restricted ourselves to only a few data points, set two computresses to the tasks, and they performed in parallel. Only in this way could we have any confidence that the results were correct. Compare

this with today when a programmer performs the task once for all and the computer aide performs a single hand-computation which is sufficient for all. Then our computers, large willing slaves, unerringly and without complaint produce all the answers you are willing to pay for.

3) Another latent computer application is any job where the payoff function varies drastically with time. Any time the marginal value of a computer solution starts out at a very high dollar value for immediate solution and goes to zero for an historical solution, a computer application may be forthcoming. Furthermore, the time constraint may cause the application to be on-line or even real-time.

payoff function

There are many present examples of this phenomenon among the military. Missile guidance, the processing associated with early warning, range safety, and fire control are but a few examples. To a lesser degree there are applications among civilian endeavors. Scheduling is frequently of this nature. From the time inventory reports come in from the field, the information for a new schedule is available. If the new schedule differs quite drastically from the old, then haste is of the essence, for the manufacturing facility is, in the intervening period, building for inventory and not for sale. This, of course, is the

motivation behind PERT and similar management control techniques. Recently, we have placed the dispatching of fire and other emergency vehicles under computer control for this reason. Furthermore, there is some glimmer of hope that information retrieval for medical purposes will be automated, since the value of timely current information to the examining doctor is, in many cases, a matter of life and death.

large file

4) Another computer application comes about any time a large file is involved and it is further necessary that this file be current and accessible by several users at the same time. Clearly, one way to have a file current is to have only one copy of that file. In addition, a computerized file can answer several requests simultaneously even if they reference the same portion of the store.

The most common example of large files in the civil domain is inventory control. Many firms have found it expeditious to automate their files to avoid over-selling fast-moving items and tying up their inventory dollar in snails. One way to achieve customer happiness is to increase the size of the inventory. While this increases customer happiness and sales temporarily, the investment in inventory may be so huge that the firm fails to turn a profit and dies.

Another approach to this is to centralize the control of the inventory (not necessarily the physical location of the stocks), and to cause a computer to

process all transactions against the file and perform the companion operations of invoicing and reordering. Quite often the savings in reduced inventory levels on the slow-moving items more than pay for the cost of the computer operation.

5) A fifth way to recognize a computer application is to find a job, any job, not necessarily large and voluminous, where sterile handling is of the essence.

sterile handling

This kind of an application would be characterized by extremely precious data. Examples of this would be in the control of classified documents within an engineering department or in the banking industry where postings are equivalent to dollar amounts.

Thus, you have been introduced to some of the more important terms of the computer field. You have been allowed to peek behind the scenes to see how we operate and that we have problems too. Furthermore, you have been supplied with handy rules of thumb which will allow you to detect a latent computer application in the event you might stumble upon one.

closing

In closing, allow me to chasten you a little bit. Such a brief introduction cannot hope to make computer experts out of you. If you think you've come across a computer application, two courses are open to you. You may pursue the course which I have taken and eventually become a computer specialist yourself. Or, you may seek out some present practitioner (either in-house or out) and request his advice and counsel.